To: DG
From: John Bercovitz <bercov@csg.lbl.gov>
Subject: a sample problem
Date: 2000/08/31
Cc: CB

Don,

Here's a sample problem. It isn't right because I don't have all the low-temp properties. I'm going to ignore that fact and use whatever values I have as if they were constant.

This is a transient thermal problem but let's hope we cool slowly enough that it's not.

I'll assume the epoxy bond line is thick enough and compliant enough that the differential is taken up there since the the base materials are so much stiffer than glue and we don't want strains in the silicon.

The CCD mount for mount model #2d has a diagonal of 49.1 mm.
I assume that the center stays put as the assembly cools. The distance from the center to an extreme corner is then ~24.6 mm.
From your graph, @ 150K, the difference in thermal expansion from room temp between Si and Invar is .00046 and between Si and AlN is .00024. So the absolute expansion at a corner (24.6 mm from center) is

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Si and Invar .00046 * 24.6 = .011 mm  absolute strain
Si and AlN   .00024 * 24.6 = .006 mm  absolute strain
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Dexter Hysol 9361 is a flexible epoxy used down to 77 K.
It cures to full properties at room temp in one week.
(Wonderful)
Shear strength is 27.6 MPa (4000 psi) @ 100K.
Tensile modulus is 724 MPa (105 ksi) @ 25C.
Poisson's ratio is .429 @ 23C.
So the modulus of rigidity is
G = E/(2 + 2 mu) = 724/(2 + 2*.429) = 253 MPa @ 25C
(By the way, I never trust this last calc to be terribly accurate.)

OK, let's say the bondline thickness is normal at 0.1 mm.
Then relative strain at the corner is

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Si and Invar .011 mm/0.1 mm = .11
Si and AlN   .006 mm/0.1 mm = .06
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We can already see we're in trouble with a bondline of normal thickness. Drat!

Now all we have to do is multiply by the shear modulus to find the shear stress:

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Si and Invar .11 * 253 MPA = 28 MPa
Si and AlN   .06 * 253 MPA = 15 MPa
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So we're at the limit for this particular epoxy with Invar, but not with AlN. Of course, we don't want to forget the numbers are bogus(!) because of the temperatures at which they are actually correct.

OK, that was the standard calculation. Now let's be more elegant about it and cut to the core of the matter. What is the maximum allowable strain for the epoxy?
gamma = tau/G = 27.6 MPa/253 MPa = 0.11 max. relative strain.
Now all we have to do is settle on a safety factor and divide absolute strain by maximum allowable relative strain to get bondline thickness.

And that suggests how to experimentally verify the data. We make a double-lap shear specimen using glass beads to set the bondline thickness, put it in something that boils at 150K, and test it in a standard tensile-test machine, of which we have many. What boils at 150K? Krypton's a good match, oh joy; imagine the expense! Hydrocarbons are flammable. Argon is a little too cold (40K too cold), but not bad, and very cheap.

John